Smooth Particle Hydrodynamics for Surf Zone Waves

Robert A. Dalrymple
Dept of Civil Engineering
The Johns Hopkins University
3400 North Charles Street
Baltimore, MD 21218
phone: (410) 516-7923 fax: (410) 516-7473 email: rad@jhu.edu

Award Number: N00014-04-1-0089
http://www.ce.jhu.edu/dalrymple/

LONG-TERM GOALS

Smoothed Particle Hydrodynamics (SPH) is a novel meshless numerical method that is being developed for the study of nearshore waves and Navy needs. The Lagrangian nature of SPH allows the modeling of wave breaking, splash-up, and the subsequent fluid turbulence, which in large part is comprised on coherent turbulent structures. Including sediment transport allows the methodology to be applied realistically within the surf zone.

OBJECTIVES

The objectives of this project are to improve the SPH model for use in unraveling the physics of breaking waves, including the description of the wave-induced turbulence and sediment transport within the surf zone. Coupling the SPH model to a vertically-averaged more computationally efficient model for larger areas would provide a computationally useful model of the full surf zone.

APPROACH

The approach is based on improving various aspects of the JHUSPH code; applying the code to more validation tests; and to examine in some detail new aspects of the model by applying it to different situations. Explorations of hydrid models, that is, coupling the SPH particle model to conventional finite difference models, such as the Boussinesq model, FUNWAVE, are being explored.

WORK COMPLETED

FYO6

- Modifications to the JHUSPH code this calendar year involve implementing a new time integration scheme, based on Beeman's (1976) method, which is O(Δt4), which is two order higher than the previous method, based on the Verlet (1967) algorithm.
- Validation of the SPH hydrodynamics calculation has been carried through comparisons to laboratory experiments.
- Development of a Large Eddy Simulation equivalent for the turbulent contributions to the sub-particle suspended sediment transport.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **Smooth Particle Hydrodynamics for Surf Zone Waves**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **The Johns Hopkins University,Dept of Civil Engineering,3400 North Charles Street,Baltimore,MD,21218**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

- Validation of the model for suspended sediment transport for laboratory experiments of oscillatory flow over ripples.
- Implementation of a scheme to identify coherent turbulent structures in breaking waves.

RESULTS

Code Improvements: The code was improved this year with the implementation of a variety of new algorithms, such as a better time-stepping method (based on Beeman, 1976) for a higher accuracy; sub-particle scaling for turbulent suspended sediment transport to account for turbulence at length scales smaller than the size of the SPH particle (consistent with the sub-particle scaling used for the hydrodynamics turbulent closure scheme); and included a new kernel (weighting function), taken from radial basis functions (Wendland, 2005), which requires much less computation than the cubic spline function we have used earlier. In addition, the decision has been made to implement a more robust numerical approximation into the SPH method. Traditional SPH uses a weighting function based on dispersed fluid "particles" or nodal points to interpolate data. It has been shown that this approach is similar to approximating a tilted plane with a constant value. Moving Least Squares (MLS) has been suggested by Dilts (1999) and others as a more exact approach to the approximation, which allows a local polynomial approximation to the plane. This is being implemented.

Hydrodynamics Validation: SPH is a robust model that provides realistic results for nearly all examples of free surface flows. Despite that, very few details comparisons to hydrodynamics are extant in the literature; in part, this is due to the need to have high resolution for these comparisons. We have been carrying out validation tests here for waves on beaches (Synolakis, 1986 and Ting and Kirby, 1995) and, with colleagues at the University of Vigo, Spain, for cases of a dam break problem with standing water in front of the dam.

In Figure 1, a comparison is made between JHUSPH results and the data (given by blue stars) obtained by Synolakis (1986) in a wave tank study of solitary waves on a beach. The motion of the wave maker, the propagation of the wave across a horizontal section, and run-up of the wave on slope, are all accurately modeled.

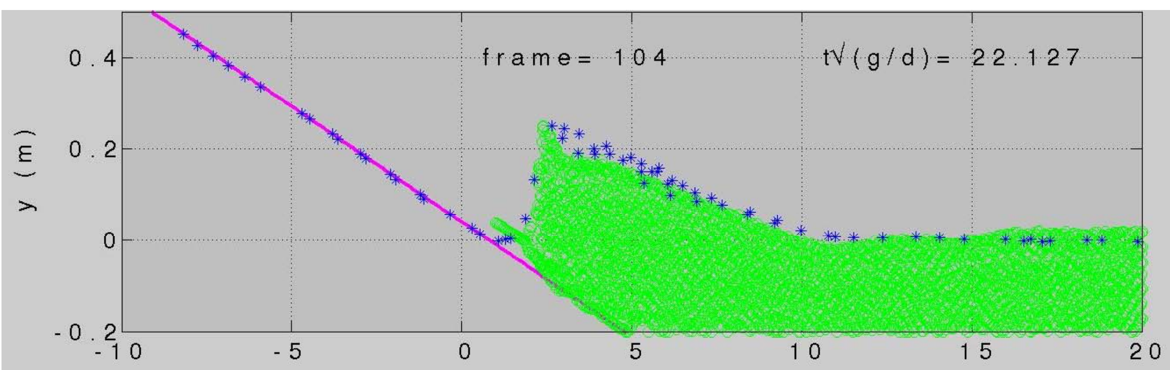

Figure 1 SPH model (in green) compared to data from Synolakis (1986) for a shoaling solitary wave.

Wave-breaking turbulence: A plunging breaker on a beach creates a tremendous amount of vorticity. It was observed in our previous numerical studies that the vertical vorticity appears in the breaking region concurrently with the breaking event and persists after breaking, evolving into coherent structures, such as obliquely descending eddies.

To identify these coherent turbulent structures, a method used in turbulence is adopted. The velocity in the small neighbourhood of each particle is assumed to vary linearly, namely,

$$U_i = A_{ij} x_j$$

where *Aij* are local components of strain rate and *xj* are local coordinates. The eigenvalues of the tensor *A* can be obtained from the characteristic equation:

$$\lambda^3 + P\lambda^2 + Q\lambda + R = 0$$

$$P = -A_{ii},\ Q = \frac{1}{2}(A_{ii}^2 - A_{ji}Aij),\ \text{and}\ R = |A|$$

P, Q, and R are the invariants of the tensor *A*. While vorticity can be precisely defined as the curl of vorticity, there is no exact definition of a vortical structure. It has been shown (*cf* . Bernard and Wallace, 2002) that in regions of positive values of discriminant *D* of the characteristic equation above, the local streamlines indicate a swirling motion about the point. Mathematically the matrix *A* will have one real and two complex eigenvalues when *D* is positive. Hence the magnitude of the imaginary part of the eigenvalue is used as a criterion to look for vortical structures.

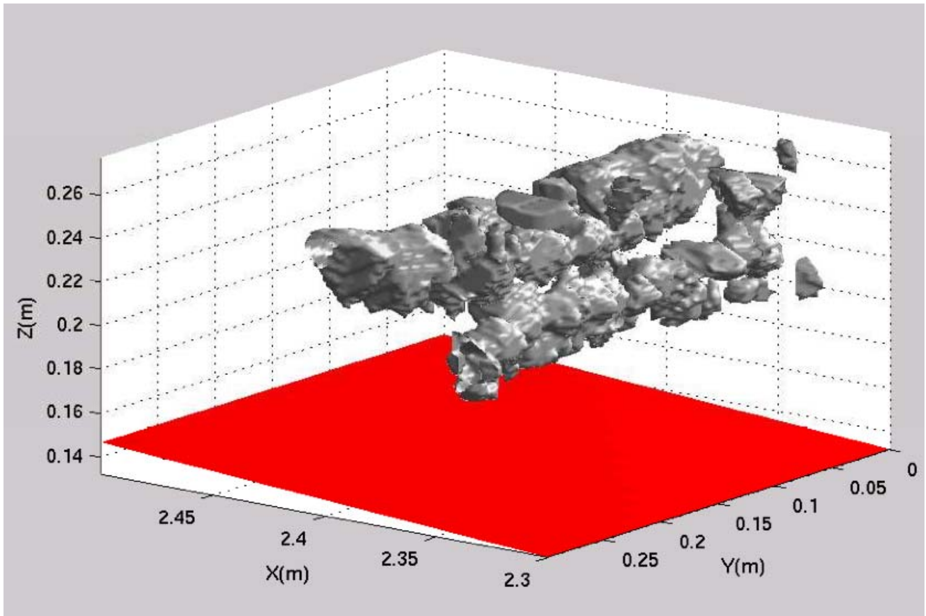

Figure 2 Coherent vortical structures under breaking wave. X increases towards the beach, Y is along shore distance, and red denotes the bottom.

For each water particle in the simulation domain, the eigenvalues of *A* are computed. Iso-surfaces of the magnitude of the complex eigenvalue equal to some small positive number are then plotted to look for vortices. Figure 2 shows an iso-surface visualization of vortices corresponding to the touchdown and rebound of a plunging breaker jet. While all the vortical structures shown in the figure above are plotted in gray, some are rotating in one direction and their neighbors in the opposite direction. These vortical structures show considerable alongshore (Y) consistency, yet there is clearly 3-D structure evolving, turning into obliquely descending eddies.

Suspended Sediment Calibrations

Our earlier examinations of suspended sediment over ripples (Zou and Dalrymple, 2004, 2006) has been extended by the development of a parallel code version of oscillatory flow in a U-tube (actually modeled by fluid in a horizontal tube bounded by moving pistons). A sub-particle scheme (like LES) was derived for the turbulent diffusion term to resolve the suspended sediment flux in eddies that are smaller than the particle "size" (the size of the compact support for the SPH weighting function).

In Figure 3, the comparison of the JHUSPH computed vertical distribution of volumetric sediment concentration over the crest and trough of wave-induced ripples of length λ. The model results compare satisfactorily with the experiments (Ribberink and Al-Salem, 1989).

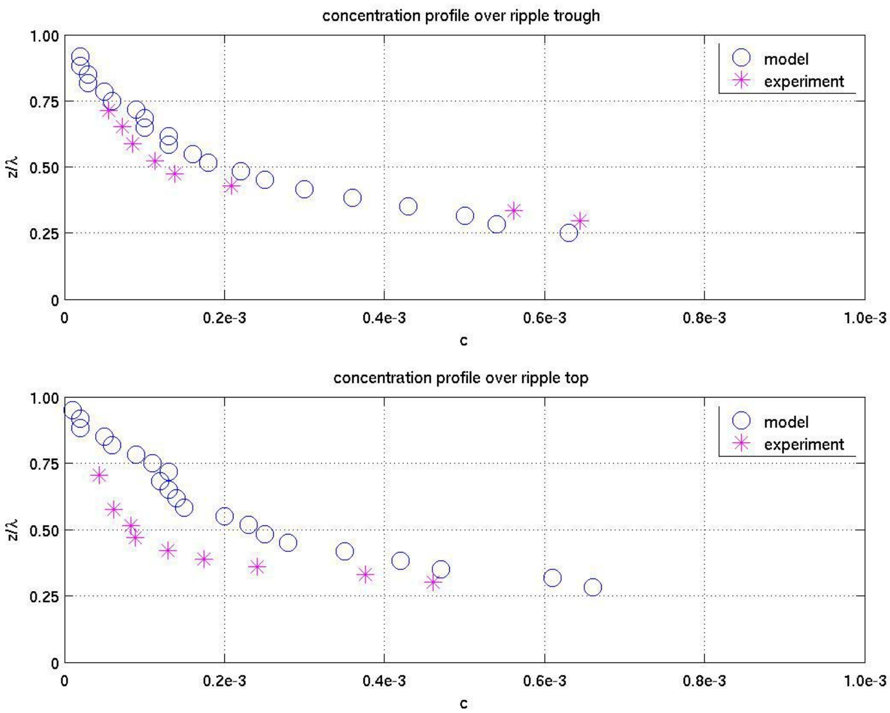

Figure 3 Volumetric concentation over ripple trough and crest as a function of dimensionless elevation above the bed. Dimensionless elevation is elevation divided by ripple length.

International Collaborations

The JHUSPH project at Johns Hopkins University, which we consider as an open source effort, has benefitted from collaborations with indiviuals from a number of European universities. This year, we have hosted Dr. Andrea Panizzo from La Sapienza, Rome; Giacomo Viccione from University of Salerno, Italy; and Dr. Moncho Gomez-Gesteira from the University of Vigo, Spain for research on SPH. Two of these individuals, plus former Post-Doc and other visitors, have played a major role in the development of a Special Interest Group of the European Research Community on Flow, Turbulence, and Combustion (ERCOFTAC) called SPHeric (http://cfd.me.umist.ac.uk/sph/). In fact, over 20% of the steering committee of this group have worked on SPH at Hopkins, and Johns Hopkins University (through the P.I.) is a foreign member of SPHeric.

IMPACT/APPLICATIONS

Smoothed Particle Hydrodynamics is proving to be a competent modeling scheme for free surface flows in two and three dimensions. Coupled with another wider-area wave model, such as Boussinesq, a hybrid SPH model would provide a large, highly resolved, look at an entire surf zone.

REFERENCES

Beeman, D., 1976. Some multistep methods for use in molecular dynamics calculations. *Journal of Computational Physics*, 20, 130–139.

Bernard, P.S. and Wallace, J.M., 2002. **Turbulent Flow: Analysis, Measurement, and Prediction**, John Wiley & Sons.

Dilts, G.A., 1999. Moving-least-squares-particle hydrodynamics-I. Consistency and stability, *Intl. Journal of Numerical Methods in Engineering*, 44, 1115-1155.

Ribberink, Al-Salem, 1995. Sheet flow and suspension of sand in oscillatory boundary layers. *Coastal Engineering*, 25, 205-225.

Synolakis, C.E., 1986. **The Run-up of Long Waves**, PhD dissertation, California Institute of Technology.

Ting, F.C.K., and Kirby, J.T., 1995. Dynamics of surf-zone turbulence in strong plunging breakers, *Coastal Engineering*, 24 , 177-204.

Verlet, L. , 1967. Computer ’experiments’ on classical fluids, I. thermodynamical properties of Lennard-Jones molecules. *Physical Review* D, 159, 98–103.

Wendland, H., 2005. Computational aspects of radial basis function approximation. In K. Jetter *et al.*,editors, **Topics in Multivariate Approximation and Interpolation**. Elsevier.

PUBLICATIONS

Crespo, A.J.C., M. Gómez-Gesteira, and R.A. Dalrymple, 2006. 3D SPH simulation of large waves mitigation with a dike, Journal of Hydraulic Research, IAHR. [in press, refereed]

Crespo, A.J.C., M. Gómez-Gesteira, and R.A. Dalrymple, 2006. Modeling dam break behavior over a wet bed by a SPH technique, *Journal of Waterways, Ports, Coastal and Ocean Engineering*, ASCE, [submitted, refereed]

Dalrymple, R.A. and B.D. Rogers, 2006. Numerical Modeling of Water Waves with the SPH Method, *Coastal Engineering*, 53-2/3, 141-147. [published, refereed]

M. Gómez-Gesteira, A. J. C. Crespo, M. M. deCastro, R. A. Dalrymple, 2006. SPH Accuracy to describe the wave impact on a tall structure. 1st SPHeric Workshop, Rome.

http://cfd.me.umist.ac.uk/sph/meetings/1stSPHERIC_workshop/Moncho_SPHERIC_2006.pdf
[published]

Narayanaswamy, M. and R.A. Dalrymple, 2005. hybrid Boussinesq and SPH model for forced oscillations, *Symposium on Ocean Wave Measurements and Analysis*, ASCE, Madrid. [published]

Zou, S. and R.A. Dalrymple, 2004. Sediment Suspension Modeling by Smoothed Particle Hydrodynamics. 29th *International Conference on Coastal Engineering*. [published]

Zou, S. and R.A. Dalrymple, 2005. Smoothed Particle Hydrodynamics simulation on sediment suspension under breaking waves, *Symposium on Ocean Wave Measurements and Analysis*, ASCE, Madrid.[published]

Zou, S. and R.A. Dalrymple, 2006, Sediment suspension simulation under oscillatory flow by SPH-SPS method. 30th *International Conference on Coastal Engineering*.[in press]

HONORS

Robert A. Dalrymple, Johns Hopkins University, Elected to the National Academy of Engineering, 2006.